Cooperative Vehicles to Facilitate the Crossing of Intersections by Emergency Service Vehicles

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Abstract: The deployment of Wireless communications, localisation and perception technologies are enabling the sharing of information between passenger vehicles and with the infrastructure. An electronic horizon could be built that will be several times larger than what vehicle onboard perception systems could provide and likely at a lower cost. As a result the situational awareness of drivers of such vehicles will be enlarged allowing driving assistance systems to be more predictive.

The results of a Use Case related to intersection safety, the crossing of an intersection by an Emergency Service Vehicle (ESV) is examined in details in this paper. The purpose is to convey the preliminary results of the technologies deployed as part of SAFESPOT, a large European project addressing safety related applications. It includes details of the various system components and analysis of the technologies deployed.

Keywords: cooperative vehicles, wireless communications, localisation, local dynamic maps

1. Introduction

Road intersections represent one of the most complex configurations encountered when traversing road networks, different type of powered vehicles converge into them with vulnerable road users traversing using intersections to cross roads.

The sound of a siren as an Emergency Service Vehicle (ESV) converges towards an intersection is a source of disorientation for drivers in the surrounding area. That is the sound waves propagate in such a manner that it is very difficult for the driver in the subject vehicle (SV) the direction of travel of the ESV. Further, many drivers either listen to their infotainment systems or telephones as they drive, with modern vehicles being almost sound-proof. Thus the sound signal of the approaching ESV may not be discernable by drivers.

For the elderly or inexperienced drivers sirens are a source of stress and apprehension that might result on the ESVs being delayed or the indirect cause of accidents.

In accidentology terms, a high number of accidents occur at road intersections despite the reduction of the number of accidents [1]. An insight into the accidentology statistics in Europe alone shows that between 1996 and 2004, almost 61.000 persons were killed in traffic accidents at intersections, in 14 major members of European Union. It represents 21% of all traffic accident fatalities [1]. In 2004 alone, out of 1.2 million injury accidents in the Europe of 27, 43 % occurred at intersections. These were responsible for 10 000 deaths [2]. The situation is more alarming in the newly industrialised countries where accidents are becoming a large societal and economic problem.

Vehicle motion in traffic environments is a “Spatio-Temporal” problem. That is there is a spatial-temporal relationship between all the entities sharing the road network. If velocity information is added in addition to contextual information provided by digital navigation maps, it is possible for machines to infer whether a risk of collision might exist. Therefore, if the spatial evolution of the vehicles is known within a time sequence, by projecting it into a digital representation of the environment; it is possible to build a world mode from which risk assessments by machines can be made. The availability of low cost wireless communications systems onboard passenger vehicles should permit the sharing of information within extended areas. Each powered entity within the road network could broadcast its ego-state information to the surrounding entities. It will then be possible to build a world model that provides an enlarged situational view of the environment, well beyond the limitations of onboard exteroceptive sensors. This results in an extended awareness for the driver and safety systems. That is, an early understanding of potential risks could be attained allowing the anticipated deployment of safety measures. This underlying concept is to be applied to enhance driver awareness for the crossing of a road intersection by an ESV, the focus of this paper.

Under the co-sponsorship of the European Community Information Society and Media, the 6th R&D Framework programme, the Integrated Project, SAFESPOT (Cooperative Systems for Road Safety) has developed a series a safety related applications using vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) or V2X, wireless communications technologies for safety related applications. Project partners included major vehicle OEMs, rank 1 automotive suppliers and leading universities / laboratories across Europe [3].

Whilst in accidentology terms, the crossing of an ESV does not represent a significant number, the rationale was to examine in detail all the technologies associated to an intersection related applications using V2V wireless communications, That is It was possible to decouple the decision making process so as to decide which vehicle had priority and instead assign priority to the ESV. This decision enables the examination on the way that messages can be generated and displayed, on the use of the communications components, the vehicle ego-state, the digital map, etc.

The organization of the paper is as follows: Section II examines the issue of road intersection safety by including statistical details that should enable to define the context within which the V2V ESV applications should operated, but also to highlight the safety problem at road intersections. A succinct description of the Use Case involving the ESV is given in Section III. This should provide an overall understanding on the manner in which the system has to operate. Section IV presents a system level description of the deployed architecture and related technologies. Section V describes the observations and results found following the implementation and a large showcase of the technologies. Finally, Section VI concludes with discussions of the main findings and an insight into areas that are considered critical for the deployment of V2V safety related applications.

2. Safety and Road Intersections

2.1 Accidents at Road Intersections

The introduction of tougher legislation and an agile la enforcement together with technological advanced in vehicle onboard safety systems has resulted in a Accidents has resulted in a sharp reduction of accidents across the European Community in recent years, though figures remain high. Figure 1 shows the statistics associated to accidents in the Europe of 27.

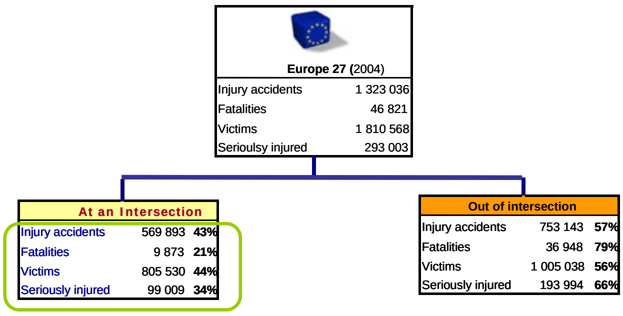

Figure 1 : Accident Statistics and Intersections [2]

In the Europe of 27 (2004): 43 % of injury related accidents occurred at intersections. Out of the overall number of fatalities, 21% occurred at intersections, with 34% of the seriously injured [2].

The design of a system that is to address intersection safety, needs to identify the context under which this occur. This should give indicators on the type of intersections where accidents occur, the type of vehicles involved, the time of the day, the age distribution of the drivers involved, weather conditions, etc. Information that is used as input on the V2V system that is to be designed. As the ESV application is to be extended to intersection safety involving all type of vehicles. The application considers the statistic results so they are part of the design. For example, 80% of intersections occur in rural areas representing a low percentage of fatalities, by contrast fatalities inside urban areas are 42%. The road structure and geometry is another source of information.

Table 1 summarises the context within which accidents occur at road intersections. The design of the ESV application takes into account the context and uses it as design constraints.

Item	Description	Data
1.-	Road Geometry	Roads perpendicular to each other (53%). 'Cutting Edge' situations represent 25% of accidents.
2.-	Type of Regulation	Intersections with traffic lights (45 % to 68%)
3.-	Environment	Rural predominant EU-27 64%, fatalities most countries
4.-	Light and Visibility Conditions	Daylight & Twilight (67% to 75%)
5.-	Weather Conditions	Normal (82% to 90%); road surface Dry
6.-	Main Actors	2- Vehicles (67% to 82 %); 1-pedestrian (9% to 14%); Passenger Vehicles, followed by motorcycles and pedestrians
7.-	Driver Age	Young Drivers and the Elderly

Table 1. Summary of Context at which road intersection accidents occur

Other considerations should be:

The Driving Situation. As a vehicle arrives to the intersection several phases exist: normal, crossing, turning, etc. 59 to 67 % of all intersection accidents occur while the driving phase was normal (i.e. there was no maneuver), with 9 to 18 % when drivers turned left.

Collision Causes. When driving conditions are normal, statistics indicate that 43 % of accidents were driver inattention, followed by 12 % as a deliberate violation of the traffic signal. When the vehicle is making a manoeuvre: 70 % will be driver inattention (did not observe the incoming vehicle) and 16 % a deliberate manoeuvre [4].

It is to note that, statistical curves representing the driver population involved in fatal road intersection accidents are dominated by both extremes of the age spectrum, that is young drivers without the necessary experience and the elderly. The later when involved at a road intersection accident have a very high index of mortality.

3. Crossing of Intersections by an Emergency Service Vehicle

The safe and rapid passage of emergency vehicles in congested environments is difficult and potentially hazardous in densely populated environments. The presence of an emergency vehicle as it approaches an intersection can be informed to other immediate vehicles, this in turn ensures that there is awareness by drivers of the presence of an emergency vehicle.

The implementation of such a use case implies that the possibility of an unforeseen situation to be avoided. In case of major incidents, messages from the emergency vehicles can be broadcasted forming a pseudo-tunnel, that becomes like a safe passage for emergency vehicles.

3.1 Use Case

The description of the Use Case follows the formalism proposed by Cockburn that was adapted and applied for all the Use Cases in SAFESPOT. The scenario in which the arrival to an intersection of a ESV together with other actors is shown in Figure 2.

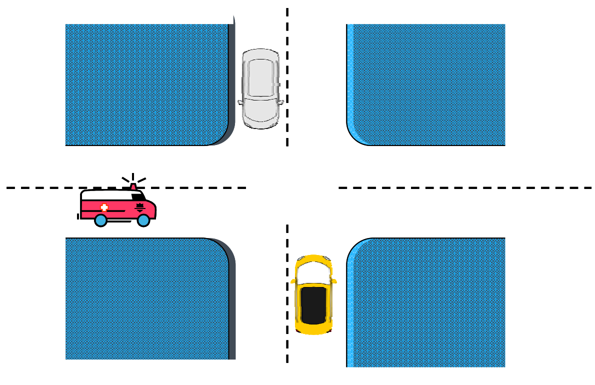

Figure 2 : Graphical Representation of ESV Use Case

Table 2 Presents a summary of the Use Case in response to which the cooperative vehicle application was developed.

Item	Description
Case Name	Approaching Emergency Service Vehicle Warning
Case ID	SP4_UC_Approaching Emergency Vehicle Warning – 1f
Short description	Assumes vehicles within the immediate environment of the Intersection are SAFESPOT type. An ESV broadcasts its presence as it nears an intersection indicating its position and expected trajectory. The system warns drivers of the arrival of the ESV or informs them to stop so this can traverse the intersection.
Purpose	To facilitate the transit of ESVs and to reduce the risk of collisions by broadcasting their passage as they approach an identified intersection.
Driving environment	The target intersections are those included in the use case are urban and rural environments and where visibility conditions are poor.
Risk's source	The possibility of other vehicles not receiving in time the information, or the wrong identification of the next oncoming intersection by the ESV system. The accuracy and latency on the relative position of the ESV with regard to the intersection.
Successful end condition	All vehicles approaching the intersection are informed of an oncoming ESV. The emergency crosses the intersection without a drastic reduction of its cruising speed and moves towards the next intersection. Only drivers involved in the trajectory of the vehicle are give way to the approaching emergency vehicle.
Failed end condition	Drivers are not informed on time of the arrival of the ESV and block unwillingly its way. They do not have sufficient time to position their vehicles out of the way.
Trigger	Detection and identification of an oncoming intersection by the positioning sensors and digital map database in the emergency vehicle, and broadcast of the information to the vehicles within its immediate environment.

Table 2 Succinct description of the ESV use case

3.2 Preliminary Analysis

A preliminary analysis a site visit was made to understand the scenario of the arrival to an intersection of an ESV vehicle and the manner in which drivers will react. For this purpose a script was written for one of the tests sites, La Brosse intersection in order to gain a better understanding of the manner in which the functionality of the use case can be assured.

A sequence of events was defined that enable the formulation of the type of information that the system will need to implement the selected use case. Figure 3 shows an instance of the scenario used for the analysis. It indicates the trajectory of the ESV, that of the SV as well as the occlusion that exists in such type of environment.

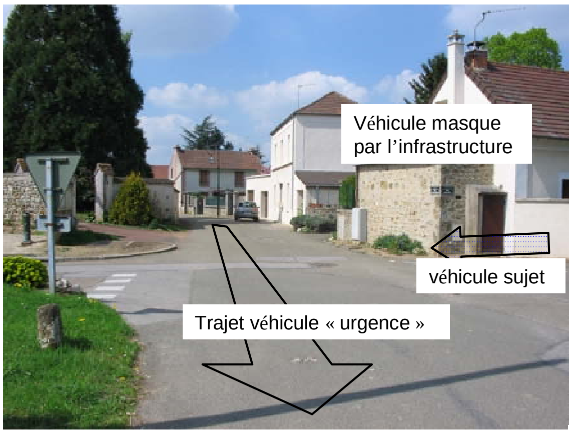

Figure 3. Spatial Context for the *La Brosse* intersection

4. System Design and Implementation: Emergency Service Vehicle Warning

The applications represent a contribution to a much larger complex system that was implemented as part of SAFESPOT. Thorough details can be found in the website dedicated to the project [3] and on the diverse applications associated to this milestone work in cooperative vehicle technologies [5]. In this section first the problem is formulated to define the information needs for the applications to be implemented using wireless communications technologies. This will be followed by a description of the system as it was implemented.

4.1 Problem Formulation

The premise for cooperative vehicles is that wireless communications between vehicles and infrastructure provide a network that allows for the dynamic sharing of information amongst entities sharing the same road network. That is, information acquired by the vehicles or infrastructure via their own sensors can be shared with other vehicles or with another part of the infrastructure.

When vehicle converge to an intersection, awareness of the presence of other vehicle resides on the attention of the SV driver, the field of view restricted by the vehicle chassis and occlusion in the environment. The introduction of active safety systems through the use of exteroceptive sensors like video cameras, radar or scanning lasers to detect obstacles in front of the vehicle have been deployed to some extend and multiple vehicle OEMs are working experimenting with them. Such sensors although enhancing safety are limited by their physics, they have a reduced field of view, they are located at heights where a long range perspective is difficult with the perception process being to found very complex and challenging. That is, it is not only a problem of detection but also of interpretation and assessment of risk. Tasks that despite multiple advances at all levels remain very challenging and their implementation could be cost prohibitive [6], [7].

Figure 4. shows the flow of information that exist when vehicles can share their ego-state information. It can be observed how the use of a exteroceptive sensor is limited by its field of view.

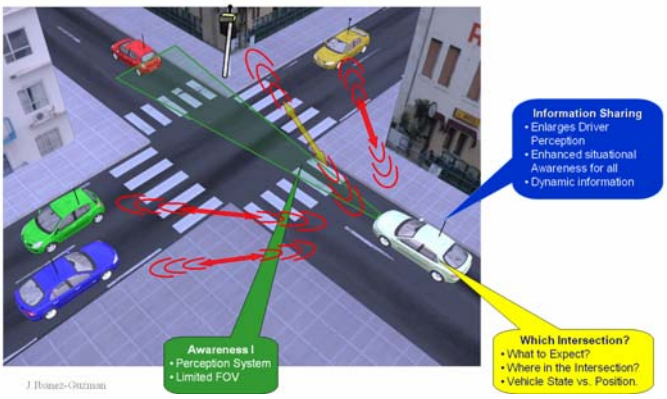

Figure 4 : Information flow thanks to V2V and V2I links

V2V or V2I communications systems will lead towards the sharing of information between the vehicles or infrastructure. Information sharing would thus enlarge the situational awareness by building a digital representation of the environment where the state of each of the relevant vehicles could be represented at a given instant and then associated. However the correlation between these positions is only effective if there is context. That is they need to be reflected in the digital representation of the road network, to determine whether vehicles are converging to the same point (an intersection) or moving away at different levels or directions.

It can be inferred that in such systems there are three fundamental functions: localization, local dynamic maps and communications. They form the infrastructure in which cooperative vehicle systems are based.

4.2 System Level Description

The design principles applied are based on the association with respect to time and the road intersection, of state variables representing the absolute position, heading and speed, of the vehicles converging to the same intersection. These are projected onto a local representation of the road geometry and associated features, called the Local Dynamic Map (LDM). The vehicle states have a certain degree of uncertainty associated to them, in particular their position information. It is very difficult to have precise information on the absolute position of each vehicle; GPS alone insufficient. In SAFESPOT different alternatives were explored with different degrees of success.

The projection of the vehicle states are projected to the LDM. This enables a spatio-temporal situation of the vehicles arriving at the intersection to be known to which their relevant speeds is associated. It is then possible to determine whether or not the presence of other vehicles near the intersection represents a risk.

The design centres in the depiction of the SV ego-state and information received from other vehicles within its immediate environment on a digital representation of the road geometry. That is, a hierarchical representation of the environment where all the information will be mapped and associated with respect to time. It requires a multi-level representation having multi-resolutions and different sizes. Each level contains static and dynamic data including the position of the hosting vehicle (ego-position) and the geo-localised projections of the vehicle states from data received via the wireless network. The principle is similar to the 4-D/RCS architecture for autonomous unmanned ground vehicles formulated by J. Albus [8].

The map structure is known as the *Local Dynamic* Map (LDM). In the automotive domain digital maps representing road geometries and associated features are used intensely in car navigation systems. These are used as the basis for the LDM. The main map suppliers TeleAtlas and Navteq are involved in the project. Separate implementations of the LDM were made; these were associated to different sites. The implementation used the Navteq version. A description of one instance of the LDM can be found in [9].

The relative position of the vehicles is another primary function, the *SV position* has to be projected onto the LDM using map-matching techniques and also the positions of other vehicles received via the wireless network. The use case is very vehicle position dependent with the spatial association requiring temporal information. This is difficult as position estimates might be at different rates with processing and transmission delays likely to occur.

As vehicles enter within the *communications* range of their onboard equipment, they form dynamic ad-how networks for information exchange. These use the 5.9 GHz frequency based on the IEEE 802.11p (allocated by the EC for V2X communications based safety applications).

The information from the SV and that in the incoming messages needs to be fused and interpreted. This is done as part of the *Situation Refinement* in the data fusion process. The SV position information is projected onto the LDM. The position of the other vehicles embedded in the incoming messages is projected in time to compensate for latencies in the system. The compensation was made via a path-prediction method, in which the vehicle position, speed and heading will be projected in time as an estimate. This projection is made to the time at which the SV ego-state is used.

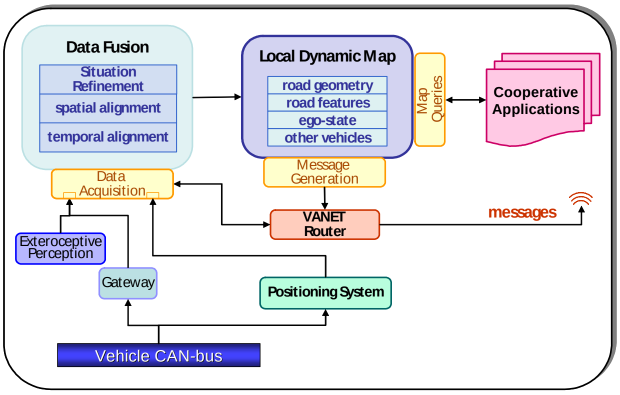

Fig. 5. SAFESPOT System Architecture

Figure 5 shows the System Architecture. The major components are the LDM, the Positioning System, VANET router/Message Generator, Data Fusion and the Application software. The later implements the use cases by generating the messages associated to the Safety Margin. The Data Fusion unit performs a very important task. It maintains the coherence of the LDM via a set of functions: Situation Refinement, Spatial and Temporal Alignment. The output of the data fusion process is the only component writing onto the LDM. The cooperative applications are triggered following events detected in the LDM. These in turn will perform some queries on the LDM regarding the spatial relationships between the SV and the other vehicles with regard to the road geometry. This information is used to decide whether or not to inform the SV driver.

The SV ego-state is generated by combining information from the vehicle proprioceptive sensors with that from the positioning system. Time stamping the information is very important for this purposes all computers clocks are synchronised using the GPS time issued from the positioning system.

4.3 System Implementation

The developments were software based to which all project partners contributed. The system consists of several PC-type computers running Windows XP and Linux OS. All computers were linked using an Ethernet switch. All the vehicles were running the same software with only the implementation of the LDM versions associated to the two map suppliers. The Renault vehicles differed on the use of an advanced positioning system that consisted of a loosely coupled GPS, odometry and an Inertial Measurement Unit. The resulting accuracy was less than a metre which makes the projection of the vehicles' positions onto the LDM sufficient for the implemented applications. The premise was to decouple the position problem and to concentrate on the applications. The systems were integrated onboard two Renault vehicles, an Espace IV and a Laguna III. A schematic representation of the implemented system is shown in Figure 6.

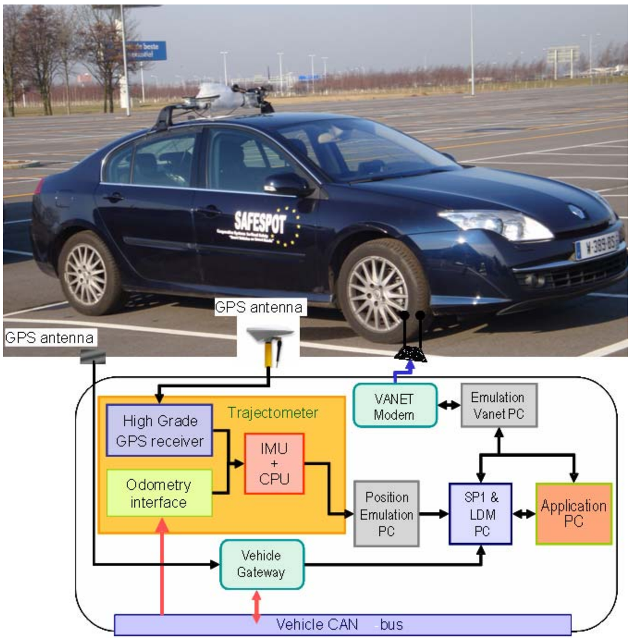

Figure 6 : Schematic representation of the implemented system

A total of four computers were used. The LDM together with information on the ego-state of the SV was hosted by one computer. A separate PC computer is used to translate the format generated from the positioning system into SAFESPOT compliant messages. It was also for logging purposes of all the data flow within the system. A different computer ran the VANET software that was in charge of routing the received messages from other vehicles and broadcasting the SAFESPOT beacon messages at 2Hz. The application computer ran the road intersection use cases. This was connected to a video monitor used to display the warnings to the driver.

The clocks in the PC computers were synchronised with respect to the GPS clock. For this purpose a NTP server was used in both vehicles.

The deployment and debugging of the application was very much facilitated by a visualisation tool supplied by the project partner Continental. This tool enable the display of a 3D view of the environment in which the vehicles transmitting their beacons were shown in real time.

5. Application and Results: Arrival of an Emergency Vehicle to an Intersection

To test the use case the following scenario was ellaborated: The ESV (Laguna III) broadcasts its presence (at 2Hz) as it approaches an intersection indicating its position and expected trajectory. The vehicles in the neighbourhood will receive this information, those close to the intersection and converging to it will be considered as relevant. Vehicles travelling perpendicular to the ESV will estimate their distance to the next intersection, and after time alignment the distance of the ESV to the same intersection will be calculated. An evaluation of the risk is made based on the vehicles speeds and distances to the intersection, plus an estimation of the distance needed for them to brake. According to this ratio, three levels of warnings can be shown to the driver (yellow, orange, red).

If the ESV travels along the same road as the SV vehicle, its presence is notified to the driver. The intensity of the warning depends on the inter-distance between vehicles. Figure 7 illustrates the concept and shows an instance of the HMI used.

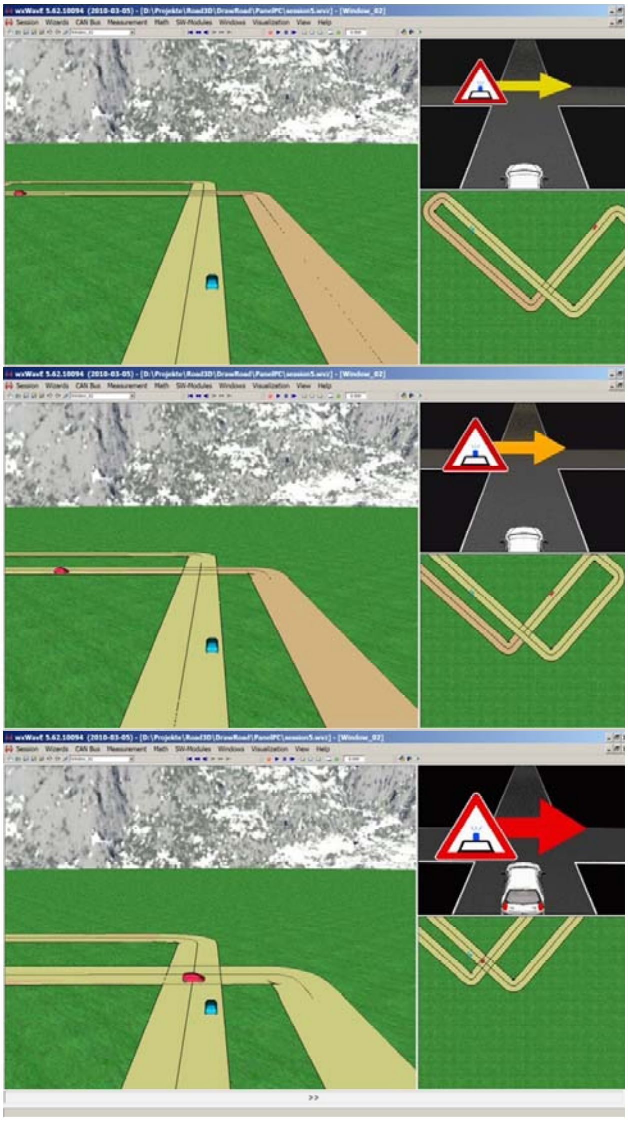

Figure 7 : Sequence for approaching ESV warning

The visualisation software is combined with the messages sent to the driver thus it is possible to associate the spatial correlation between the vehicles, the intersection and the message sent to the driver. Via this tool it was possible to observe what the decision making process was observing so as to assess whether a warning was generated to the SV driver on time.

Trials were conducted at La Brosse (France) area and at the Satory test track (near Guyancourt, France). The first is next to a village whilst the second is a vehicle test site. Vehicles were run at speeds between 20 and 70 Km/h, the upper limit being a safety constraint. Warning signs will appear on a video screen, as shown in Figure 7 when the application was triggered. External parties unfamiliar with the project drove the vehicles at the Satory test track. These were managers in charge of evaluating active safety systems. The application was well perceived and the effects of the warning messages were sufficient to act on time on the vehicle.

Not only the ESV warning was tested but also other intersection related use cases developed by Continental. These were: An accident at an Intersection, one of the vehicles pretends to have an accident while another vehicle approaches the intersection. Obstructed view at intersection, in this case the vehicle obstructing the line of sight was a non SAFESPOT vehicle. Permission Denial to go ahead, one vehicle is standing at the intersection while the other one is approaching. Only visual warnings are given. The most complex use case relates to the Approaching Emergency Vehicle

Figure 8 : Vehicles at the Mobility 2010 showcase

Warning. It uses the full SAFESPOT architecture and V2V communications with both vehicles in motion. The later was demonstrated at the Satory track site where vehicles were driven by people unfamiliar with the technology.

The use cases were part of the final demonstration of SAFESPOT applications made at Amsterdam, during InterTraffic 2010, the Mobility Showcase. For this purpose an intersection road geometry was traced on the test track and a joint demonstration prepared with the LIVIC in which not only the intersection applications were demonstrated but also a V2I application was ran in which dynamic information was transmitted from the infrastructure to the vehicles. Figure 8 shows a picture of the vehicles during the Mobility 2010 showcase a total of nearl 400 visitors were hosted in the SV.

5.1 Observations

Wireless Communications Links. The frequencies at which the communication devices operate (5.9 GHz) make them sensitive to obstacles. The vehicles communicate when they are within line of sight of each other. When this occurred, communications could be established up to 700 m with packet loss fewer than 8%. However, a thin wall of trees obstructing the line of sight will break communications even at 50 m (25% packet loss). Better performances could be achieved with better antenna layouts or different modems. Other test included the use of four vehicles at speeds up to 70 Km/h without a perceptible reduction in performance. During the InterTraffic demonstration, up to 20 nodes were in operation within a confined space, there was not performance reduction.

Map-matching algorithm. The position of vehicles received from the V2X network was not always easy to project them into the LDM. The reason is that information held by the SV about another vehicle (known as the Principal Other Vehicle - POV) is not always sufficient. As a result the system onboard the SV will not be aware that the two vehicles are heading towards the same intersection, and hazardous conditions might arise. During one of the field experiments when the SV and POV were at ~500 m apart, and driving towards the same intersection, without any communications break. At times the position of the SV was associated to the wrong road despite using the high-precision IMU-based localization system. This was unexpected, as data used by SV and POV to localize the POV is of the same precision. It is likely that the main difference resides in the information received by the SV about the position of POV via V2V communications. It was observed that the link is not ideal. When the vehicles are far some messages were lost. The lack of positioning data, coupled with inaccuracies in the digital map geometric descriptions, plus the likely weakness in the map-matching function, leads to a large initial error in the trajectory estimation. The POV as seen from the SV is assigned to the wrong road with the error being propagated through the rest of the experiment. The position of the vehicles will be interpreted as not converging to the intersection. Vehicle localization is a major issue for situational awareness.

4. Conclusion

Road intersections represent a high percentage of accidents and a source of stress to drivers hence the interest. In this paper, the approach taken for the design of cooperative intersection systems was based on accidentology data was presented for the safe crossing of an emergency service vehicle. The software components were developed within the SAFESPOT project. Passenger vehicles were used to demonstrate how vehicle-state variables could be exchanged to enhance regions of situational awareness, at speeds comparable to those found in real traffic conditions. The developments were software based implemented on COTS equipment. This spatio-temporal problem was constrained by the use of the Local Dynamic Map to represent the world where all applications infer their data.

Experiments showed the limitations of the wireless networks, the need for clock synchronisation and time stamping, and for means to compensate for communication delays or breaks as well as for data time alignment. The importance of localisation systems in cooperative vehicles was highlighted.

The testing of these systems remains a challenge in terms of resources, other than the test site, drivers, etc. means to quantify and log results are needed. Further, to trigger safety mechanisms, hazardous situations must be created, this implies a level of risk limiting evaluations. Large scale tests must take into account these considerations, and likely a combined strategy is needed, trials in dedicated sites and standard traffic conditions.

Future work will centre on the building of a digital representation for decision making that is maintenance of the LDM whilst writing in it the data received from the VANET network. Data Fusion should play an important role to compensate delays in the messages transmitted by the other vehicles as well as for the time alignment of data.

5. Acknowledgement

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